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CONSIDERATIONS OF
THE ECOLOGICAL FOUNDATION OF
NATURAL FOREST MANAGEMENT
IN THE AMERICAN TROPICS

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SUMMARY

The research base for tropical forest management is solidifying rapidly but substantial weaknesses persist. To contribute to the maintenance of tropical forest, researchers need to emphasize the species for which these forests are being exploited and the processes upon which the continued productivity of these species depend. Too much research that is tangential to pressing management issues is carried out in the name of conservation and sustainable forest use. The capacity to conduct applied research in the tropical forest of the Americas also needs to be enhanced, and funds for problem-solving studies related to multiple-use management need to be made more readily available.

In this paper some of the strengths and weaknesses in the knowledge base for natural forest management in the American tropics are outlined, starting with flower production and pollination and ranging through seed and seedling biology, tree growth, population biology, and harvesting problems. The carbon-offsetting potential of tropical forest management is presented as an example of how global concerns might provide incentives for improving management practices. Some reasons for the apparent weaknesses in the data base for tropical forestry are then suggested. The paper concludes with a brief discussion of three very different approaches to natural forest management used in Mexico, Suriname, and Peru.

CONTENTS

INTRODUCTION

Natural forest management (NFM) is a land use in which commercially valuable forest products are extracted from forested areas in ways that allow retention of substantial canopy cover. There are no clear lines demarcating NFM from other land uses; in this paper I include under the rubric of NFM land use intensities ranging from the extraction of non-timber forest products (NTFPs), like latex and seeds, to controlled selective logging and enrichment planting of native timber species in gaps created in the canopy expressly for this purpose. Emphasis, however, is on silvicultural systems that encourage natural regeneration, because in many cases the need for enrichment planting is an indication of the failure of the silvicultural approach or harvesting method, or an inappropriate harvesting intensity.

Natural forest management is an alternative to the more destructive but more familiar practices of replacing forest cover with agricultural crops, pastures, or tree plantations. A major motivation for NFM springs from the observation that if people cannot benefit sufficiently from using forests, the forests will be lost (e.g., Anderson, 1990; Panayotou and Ashton, 1992, Sharma, 1992). After reflection on the small portion of the landscape and the small fraction of species that can reasonably be expected to be maintained in parks and other types of preserves, many conservation groups are embracing NFM (e.g., Buschbacher, 1990). Finally, whereas deforestation is often driven by poverty, one premise of this paper is that many people could achieve and sustain a higher quality of life through forest management than through conversion of forest to other land uses.

A number of recently-published literature reviews on NFM have emphasized silvicultural systems tested or used in the tropics (e.g., Schmidt, 1987; Lamprecht 1989, Buschbacher 1990). In spite of the fact that attempts to transfer entire silvicultural systems from one forest to another are ill-advised at best (Hutchinson, 1988; Putz, 1992), debates between proponents of different systems rage on and many people still seek a single approach to NFM that is appropriate for all tropical forests. In this paper I will avoid these counterproductive debates, but instead will describe some components of the basic data base for NFM in the American tropics.

This paper represents an attempt to summarize the ecological basis for natural forest management. A broader but less synthetic review of the literature on NFM in this region is available in the form of a recently published annotated bibliography (Putz and Pinard, 1991). To set the stage, I begin with a discussion of the often vague and generally difficult concept of sustainability. Then, starting with reproductive biology and proceeding through physiological ecology and population biology of commercially valuable forest species, I examine some of the consequences of harvesting and silvicultural treatments. These are followed by my personal and undoubtedly biased impressions of why the ecological basis of natural forest management is weak and how the situation might best be improved. Although there are clear benefits of managing for non-timber forest products (e.g., Ashton and Panayotou 1992), timber harvesting is generally more lucrative as well as more ecologically damaging and thus receives the majority of my attention. Furthermore, although there are few specific data on the topic, timber management generally seems compatible with management for non-timber forest products (Dickinson *et al.*, 1991). The paper closes with three brief descriptions of case studies selected to indicate the variety

of silvicultural options available for use in the American tropics.

THE SUSTAINABILITY ISSUE

Any discussion of forest management must attempt to come to grips with the issue of sustainability. The vagueness of this concept (Redclift, 1991) and a multitude of definitions of sustainability (e.g., Pezzey, 1989; Gale and Cordray, 1991), make the issue difficult and controversial. In this paper, I concentrate solely on biological sustainability and the sustainability of profits derived from forestry operations, avoiding the social aspects of sustainability (i.e., sustainable development). Even with this narrow focus, discussions of forest management sustainability (sensu strictu) are complicated by questions of the temporal and spatial scales at which sustainability should be assessed. The problem is that, given enough time and enough forest, almost any harvesting intensity is sustainable. Discovery of charcoal in the soils of what was once considered "virgin" Amazonian forest (Sanford et al., 1985) has made ecologists well aware that forest will indeed recover from even drastic perturbations.

Claims of sustainable timber yields from future cuts are often made on the basis of what could only be described as equivocal data. In particular, when they bother to attempt quantification of the consequences of logging, defenders of a particular harvesting intensity often include in their calculations of future harvests more species and smaller trees than in current harvests. While timber outturn may thereby be stable over time, biological sustainability is in serious doubt.[1]

Biological sustainability analysis is complex and the criteria upon which such analyses are based are not widely accepted. Any forest manipulation that includes harvesting or stand improvement treatments will cause changes in the relative abundances of different species and modification of their size class frequency distributions. So called "selective" logging systems by their very nature, for example, do not call for the random selection of a subset of trees to be felled. Stand improvement treatments in mixed-size ($\approx$ mixed-age) stands enhance the growth and stocking of trees of commercial species at the expense of non-commercial species. Individuals of marketable species that are unlikely to yield salable products (e.g., due to poor form, damage, or the presence of wood-rotting organisms) generally are also killed, at least when competing with potential crop trees. Where even-aged silviculture is practiced (e.g., strip clear cuts), effects on relative abundances of species and size-class frequency distributions are probably even more dramatic.

One criterion for assessing the biological sustainability of forest management operations pertains to the maintenance of biological diversity. If biodiversity is defined in terms of species richness, NFM itself is unlikely to have a substantial effect on biodiversity, at least compared to the effects of conversion of forest to pastures or agricultural fields. As an extreme example, after clearcuts on hillsides in an area

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[1]It should be pointed out, however, that decisions about harvesting intensity are seldom made by silviculturalists.

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that receives in excess of 5000 mm of rainfall per year in southwestern Columbia, the forest reportedly recovered 50% of its tree species richness within only 7 years (Faber-Lagendoen, 1991). Selective logging is even less likely to lead to the complete extirpation of species. Populations of mammals, birds, and other animals are influenced by forestry operations; some species benefit and some suffer (e.g., Johns, 1985). Species loss, when it occurs, generally seem due more to hunting rather than to timber harvesting or silviculture per se (pers. obs.). Construction of logging roads and the creation of a local market for wild game (e.g., in logging camps), however, almost unavoidably intensify hunting pressure. This indirect effect should not be discounted, but should be distinguished from the direct effects of forest management. It is not clear how loss of biodiversity due to hunting should be included in assessments of sustainability of silvicultural operations. It is also not clear that maintenance of biodiversity should be the sole or even the major criterion upon which sustainability is judged; stands with similarly long lists of species could be dramatically different in structure, composition, and ecosystem function (e.g., nutrient retention).

At what spatial scale should the sustainability of forestry management operations be assessed? Certainly species richness will be easier to maintain in large managed areas than in small tracts. Should assessment be by stand (e.g., 5-100 ha), by compartment (e.g., 100-1000 ha), by concession, or entire land holding (e.g., 1000-100,000 ha)? At what population density should species be considered to have suffered irreparable damage? When they are extinct? Or when the population drops below 50, 500, or some other more-or-less arbitrary number? Populations of some long-lived species remain in managed areas but produce no young; over what time scale should population viability be assessed?

From the perspective of nutrient dynamics, management practices are not sustainable if they call for the removal of greater quantities of nutrients than are released from weathering of soil parent materials or are deposited in rainfall, dust, siltation, and so on over some reasonable period of time (e.g., Jordan 1985). Wood generally has a low nutrient concentration but whole-tree harvesting systems may result in a serious loss of nutrients because of the removal from the ecosystem of nutrient-rich bark. Any calls for intensification of logging should be made in light of potential negative effects on nutrient budgets (Ewel and Conde, 1980). Although biogeochemical sustainability is important, it is unlikely that many forest managers will measure the rates of nutrient inputs and outflows under different harvesting regimes (but see Poels, 1987).

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ECOLOGICAL CONSIDERATIONS IN NATURAL FOREST MANAGEMENT

Plant Reproductive Systems and Pollinators

Forest managers should be cognizant of the reproductive systems of the species for which the forest is being managed. Reproductive failure and genetic deterioration are potential consequences of disregarding requirements for reproduction, especially when population densities are naturally low or reduced by extraction and logging damage. Considering that many tropical species under natural conditions are represented by one or fewer reproductively mature individuals per hectare (e.g., Hubbell and Foster, 1987), harvesting could easily lead to drastically reduced seed set by the remaining individuals. If one also considers that most canopy tree species are not self-fertile (Bawa *et al.*, 1985; Schatz, 1990: Appanah, 1990), deterious effects of extraction on future populations are extremely likely. Information on reproductive systems and the effects of increased spatial isolation from conspecifics unfortunately is not available for the vast majority of commercially valuable plants.

Future populations of commercial plants will also suffer if populations of their pollinators are diminished. Wind pollination is rare in tropical forests (Schatz, 1990) and thus forest managers need to assure the maintenance of ample populations of pollinating animals. This is difficult when the pollinators are not known: unfortunately, this is generally the case. Dramatic instances of dependence on particular pollinators, such as the threat to *Durio zibenthus* (durian) fruit production in Malaysia due to quarrying of the limestone outcrops in which the pollinating bats roost, in conjunction with cutting of mangrove trees (*Sonneratia* spp.) that provide the bats with an alternate food source, (Lee, 1980) may be rare but give cause for concern. Pollination of *Bertholletia excelsa* (Brazil nuts) is another instructive case: reportedly, populations of the bees that pollinate this commercially valuable species are severely diminished by fire. Seed production in Brazil nut plantations, however, apparently can be enhanced by leaving strips of natural vegetation between the nut trees and by planting other species upon which the pollinators feed (e.g., *Bixa orellana* and *Passiflora* spp.; Brune, 1990).

Whereas many canopy tree species produce relatively small flowers that are visited by small to medium-sized insects, most of the attention of pollination researchers is focussed on what are unusual modes of pollination for canopy trees, for example hummingbirds and euglossine bees (for a recent review see Schatz, 1990). With current canopy access technology (e.g., construction cranes and canopy walkways), studying pollination of canopy trees is feasible and should be encouraged. At the very least, managers need to know what pollinates the plants for which the forest is being managed, how far pollinators transfer pollen, and the effects of forest management operations on populations of these pollinators.

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Phenology

In forests with little advanced regeneration (e.g., with few seedlings, saplings, and poles of canopy tree species) or few advanced residuals (e.g., trees less than harvestable size), the likelihood of sustainability will be enhanced if harvesting is carried out after seed crop production. If phenological patterns of the commercial species such as time of flowering, fruiting and seed production are not taken into account when logging plans are prepared, future harvests can be jeopardized. The forests of Mexico's Yucatan Peninsula provide an excellent example of this problem.

The major timber species on the Yucatan is *Swietenia macrophylla* (mahogany). In forests managed under the *Plan Forestal Estatal* (formerly the *Plan Piloto Forestal*), logging is carried out during the dry season (January-April); during the rainy season the 'oggers prefer to be self-employed tapping chico-sapote trees (*Manilkara sapote*) for latex (chicle) and are involved in agricultural activities (Arguelles, 1991). Mahogany seedlings are light-demanding and apparently do not persist long in the forest understory (e.g., Snook, 1989). One problem with relying on natural regeneration of mahogany in these forests is that seeds of this species ripen towards the end of the dry season, and thus many trees with unripe seeds are felled every year. Managers of these forests are aware of this phenological problem and are attempting to compensate for it through enrichment planting and the retention of seed trees near log yards (Arguelles, 1991; Dickinson *et al.*, 1991). For most forests, however, phenological data are not available and grave ecological errors could be made without the awareness of forest managers.

A number of researchers have suggested that maintenance of pollinator populations and effective pollinator and seed disperser service depends on the relative timing of flowering of a number of plant species (e.g., Stiles, 1979; Snow, 1986). Presumably, if species in these complementary sequences are eliminated, the other species suffer. Although most of the research on this controversial topic has been carried out on understory species, researchers in Asia have suggested a similar phenomenon for many important timber species in the *Dipterocarpaceae* (e.g., Appanah, 1990). They suggest that populations of the thrips that pollinate these tree species build up when the first species flowers and that subsequent species in the sequence depend on these augmented pollinator populations. Forest managers in the American tropics need to know if there are instances of phenological complementarity involving commercial species and how these interspecific complexes can be maintained intact in harvested stands.

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Seed Production

In devising a harvesting system, one of the most basic pieces of necessary information is the age or size[2] of first reproduction of the commercial species. The higher the proportion of reproductively mature individuals harvested during each cutting cycle, the more critical this information. For example, harvesting all trees > 40 cm dbh will within very few cutting cycles eliminate the population of a tree species that first reproduces only after reaching 50 cm dbh. The few trees that may escape harvesting are likely to be of poor form and may have underlying genetic defects.

Regrettably, little is known about the size or age at which tropical trees begin to reproduce (but see Appanah and Abdul Manaf, 1990). Some information can be gleaned from floras, and a search of herbarium records might be warranted. Due to intraspecific genetic variation, site effects, and the effects of silvicultural treatments on tree reproduction, however, such information will be of limited reliability; specific data are needed for each population and set of environmental conditions of interest.

Trees in the *Dipterocarpaceae* in Southeast Asia provide an example where size of first reproduction of timber trees may be of great consequence in determining the sustainability of timber harvesting. Under plantation conditions (well-illuminated, reduced below ground competition, and rapid growth), many dipterocarp species first flower and set fruit when only 25 cm dbh (Ng, 1966). However, Leighton (pers. comm.) reported that in Kalimantan, 60 cm dbh is a more common minimum size for reproductive maturity. If this latter estimate is correct, the 50 cm dbh minimum diameter limit for felling under the Indonesian Selective Felling and Planting System (TPTI) raises concern about population viability even in the short term (i.e., 1-2 cutting cycles of 30 years each). Appanah and Abdul Manaf (1990) report that smaller trees reproduce in logged forests in Peninsular Malaysia, but this needs funding to be confirmed in other forests.

The effects of logging on seed production by retained individuals of commercial species has apparently not been investigated in the American tropics. Viana (1990) makes a strong case for the relevance of such studies to forest management. The retention of seed trees does not assure future stocking if isolation results in severe and prolonged physiological stress, or greatly increases susceptibility to mechanical damage. Furthermore, we need to know how far seeds that are produced by isolated and forest edge plants travel and the extent to which seed crops suffer pre- and post-dispersal predation.

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[2]In most tropical tree species, age determination is difficult because they lack annual growth rings (for a review see Bormann and Berlyn, 1981). When age and size are poorly correlated, size is a more convenient and preferable parameter (e.g., Werner and Caswell, 1977).

Seed Dispersal, Predation, and Germination

Studies on seed dispersal are difficult to conduct but data are needed on the distances seeds travel in managed forests. Rough estimates of dispersal distances can be derived from research conducted in old-growth forest (e.g., Augspurger and Franson, 1988). Because wind and the behavior of seed-dispersing animals vary with forest structure and composition, such extrapolation must be made with caution. For example, seed movement into clearcuts from forest edges is likely to be influenced by the lack of perches suitable for use by seed-dispersing birds (e.g., Guevara *et al.*, 1986). Even light selective logging can have severe negative effects on bird populations (Thiollay, 1992) and perhaps on seed dispersal as well.

The comments on the need for research on seed production and dispersal in managed forests pertain to studies on seed predation, as well. The vertebrate and invertebrate seed-eaters that can so greatly influence the probability of seed survival are themselves greatly influenced by stand conditions. Ecologists developing forest regeneration strategies for abandoned pastures in Amazonia, for example, have recommended planting large seeds because predators of such seeds are rare in pastures. The resulting seedlings compete well with grasses and recover rapidly from defoliation by leaf-cutter ants (Nepstad et al. 1990).

Although germination in most tropical plants occurs when seeds are kept moist and warm, some species have additional requirements for germination of which forest managers need to be aware. One common additional requirement is a high ratio of red-to-far red light (i.e., photoblastic seeds). Species indicated to have photoblastic seeds are generally light-demanding, fast growing, short lived, and small seeded plants characteristic of severely disturbed areas (e.g., Vazquez-Yanes and Orozco S., 1984). While few timber tree species apparently have photoblastic seeds, this trait is found in several species with potential for use in biomass plantations or for pulpwood. Many species with photoblastic seeds become extremely common along logging roads, skid trails, and other areas where mineral soil is disturbed. It has been suggested that removal of leaf litter stimulates germination because dead leaves affect the quality of transmitted light in a similar way as living leaves (Vazquez-Yanes, 1988). Mineral soil disturbance may directly stimulate germination (Williams-Linera, 1990), but these two factors (i.e., litter removal and soil disturbance) have not yet been clearly distinguished experimentally. Pioneer plants may compete with crop species (i.e., act as weeds), but may also serve as nurse crops that reduce vine infestations and provide shade over crop trees that otherwise suffer if exposed to full sun (pers. obs.).

Leaf litter may also be inimical to seed germination and seedling establishment due to its mechanical instability and tendency to desiccate rapidly. Small seeds, in particular, and the seedlings to which they give rise, often suffer drought stress if suspended on loosely packed leaf litter above more moisture-rich mineral soil. Leaf litter removal or mineral soil disturbance may therefore benefit seedling establishment and may help explain the concentration of small seeded pioneer plants on soil disturbed by uprooted trees (Putz, 1983) and in areas severely disturbed during logging.

Seeds of some species germinate only after being scarified by gut passage through birds or mammals or mechanically when abraded by soil particles (for a review see Vazquez-Yanes and Orozco S., 1984). Both scarification processes generally enhance the rates at which seeds germinate, but do not influence

the overall percentage germinating (Lieberman and Lieberman, 1986). Seeds of some species from dry environments germinate only after being flushed of water-soluble inhibitors on their seed coats; this characteristic is apparently unknown in tropical forests and is unlikely to be of much consequence if it does occur. Rapid and more-or-less simultaneous germination are useful characteristics in nursery management but seem of little consequence in NFM.

Light Requirements, Nutrient Requirements, and Responses to Competition

To manage a natural forest properly, the post-germination light requirements of commercial species need to be known. Although most canopy species survive and grow better in sun than in shade, shade tolerance is a matter of degree and is difficult to determine. While shade tolerant species tend to have dense wood, deep leafy crowns, and abundant seedlings and saplings in the shade (i.e., reverse J-shaped size-class frequency distributions), reliance on these correlations is often misleading (e.g., Knight 1975).

Determination of optimal light conditions for photosynthesis (i.e., light compensation points and saturation light intensities) is also problematic due to developmental changes, effects of prior conditions, and reduced disease resistance of plants grown under shaded conditions. Furthermore, in the forest it is often difficult to separate the effects of shading from those of root competition; presumably both are reduced under canopy gaps. Finally, in addition to total daily measurements of light intensity, duration of sunflecks as well as the wavelengths of incoming light are also important in many instances (Chazdon and Pearcy, 1991).

Plant species differ in their nutrient requirements and in their responses to fertilization (e.g., Chapin, 1980). Although the distributions of some tropical species are broadly correlated with soil fertility, experimental data on growth responses to soil conditions are only available for a few species grown in plantations (Lamprecht, 1989). This lack of information is a serious problem. For example, although the costs of forest fertilization are generally prohibitive where silviculture is not intensive, fertilization of enrichment-planted seedlings and natural advanced regeneration might decrease costs of future treatments (e.g., weed control) if growth is markedly accelerated. The experiments that would provide silviculturalists with the information they need about plant responses to soil fertility are neither complicated nor costly, but apparently are rare.

Drought resistance, particularly of seedlings, often determines the success or failure of forest management practices (Smith, 1986). Tolerance of water deficits, in contrast to nutrient and light requirements, is relatively easy to measure in the field (for a review see Bazzaz and Pickett, 1980). One advantage of using natural regeneration is that it can generally be assumed that the moisture regime of at the site is appropriate for the species represented. This is not necessarily the case, however, where enrichment planting is conducted and where site conditions have been drastically altered by silvicultural or other treatments (e.g., Primack et al., 1987).

Species differ in competitive abilities and in their capacity to respond to favorable environmental

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modifications. Unfortunately, attention of ecologists interested in competitive abilities have focussed mostly on short-lived herbaceous species from the temperate zone. Virtually nothing is known about competitive abilities of tropical plants. There are even conflicting reports about responses of advanced regeneration to release from apparent competition (i.e., crowding) during stand improvement treatments!

On the nutrient-poor and often severely or poorly drained sites that constitute most of the permanent forest estate in the tropics, below-ground competition is likely to be severe (Poels, 1987; Putz and Canham, 1992). If this is the case, enrichment planting techniques might be profitably modified by planting seedlings in excavated holes, such that adjacent roots are cleared away, rather than in dibbled holes or slits cut with a machete (for reviews of enrichment planting in the tropics see Catinot, 1969; Weaver, 1987).

Temperate forest tree species differ markedly in their responses to canopy opening after extended periods of suppression (e.g., Smith, 1986). Stand improvement treatments should reflect the likely responses of the target species, but this information is unavailable for most tropical taxa.

Population Biology, Harvesting Schedules, and Yield Estimates

Inventory data and estimates of growth and mortality rates provide the appropriate basis for harvesting schedules and yield estimates. These data are most useful if incorporated into stand or population projection models (e.g., Usher, 1966; Vanclay, 1989; Getz and Haight, 1989; Peters, 1990). While the basic data can be extracted from growth and yield monitoring plots, quite a bit of biological knowledge is needed to assure the reasonableness of model predictions. For example, in models of species-rich forests it is generally necessary to group species on the basis of growth rates, timber qualities, and responses to silvicultural treatment. It is also important to restrict application of stand models to stands growing under the conditions on which model parameter estimates were based.

Stand-projection models are generally based on estimated rates of tree diameter growth, mostly because diameter is easier to measure than changes in biomass or height. From these data and volume measurements of felled trees, equations can be written to estimate volume increments of standing trees. Growth rates differ greatly between species and reliable estimates for a single species in a single forest generally require hundreds of tree years (e.g., at least 5 years of growth data for 10 trees in each of 10 dbh classes; e.g., Putz and Chan, 1986). Design of monitoring schemes should reflect that growth rates vary with environmental conditions at the scale of the individual tree, stand, forest, and region.

How to use these data is also problematic. Mean growth rates of trees in a diameter class are generally inappropriate to use in projection models because trees in dense stands growing at the average rate or slower often do not grow to become the next harvestable crop. Furthermore, growth rates are often more rapid during the first 5-10 years after logging, slowing down later in the cutting cycle. Finally, at the population level, growth rate distributions are seldom normally distributed, thus making the arithmetic mean an invalid and potentially misleading descriptor.

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Mortality rates need to be accurately estimated in constructing stand projection tables. Even more data, in terms of tree-years, are needed than is the case for diameter growth estimates. Death is often episodic and spatially clumped in natural forests (e.g., Lawton and Putz, 1988; Hubbell and Foster, 1990), making reliable estimates difficult to obtain. Given the spatial variation caused by logging, heterogeneity in mortality rates is likely to be even more pronounced in logged forests. Fairly large numbers (4-5 per forest) of large plots (1-2 ha) monitored over long periods of time (5-10 years) are needed. Models can be run with less data, but they need to be updated as data become available. Although data from the stands of unlogged forest favored by tropical ecologists provide some clues about relative growth rates, permanent plots intended to provide data for stand model construction need to be located in logged and silviculturally treated forests. Plots established before logging can yield additional data on damage during the harvest and on changes in growth rate in response to stand opening.

Recruitment estimates are also needed for stand modeling. Some data from natural forests are available (e.g., Garwood, 1983), but minimum size for inclusion in the sampled population varies greatly among forest ecologists and modelers. Recruitment estimates with lower diameter limits of 10 cm dbh or even 1 cm dbh need to be supplemented with data on seedling establishment in more intensively studied subplots.

Populations of seedlings and saplings are generally quite responsive to changes in environmental conditions and can provide early warnings of the long-term consequences of stand manipulations. Recruitment rates vary greatly between species and in response to stand treatments. For example, heavy logging often leads to substantial recruitment of light-demanding species but may decrease stocking of more shade-tolerant species.

Unfortunately for natural forest managers practicing silviculture in mixed-age stands, there is no clear equivalent of the "site index" (e.g., height of the five tallest trees in the stand after 20 years) used by plantation foresters to assess site quality (e.g., Smith, 1986). Site quality in natural forests is usually based on the much less rigorous criteria of apparent soil conditions, topographic position, stand structure, and species composition.

Where sufficient data on forest structure and growth are available, the effects of different harvesting intensities and stand improvement treatments can be predicted with elasticity analyses of stand projection models (e.g., Caswell, 1989). Such matrix manipulations seem to work better for single species models (e.g., Pinard and Putz, 1992) than for entire stands (e.g., Shugart, 1984; Vanclay, 1989), but the possibility remains for predicting changes without actually carrying out the manipulations. To the extent that results of elasticity analysis are reliable, silvicultural operations should reflect their predictions. Pinard's (1993) study of *Iriartea deltoidea*, a palm harvested for timber in Brazil, provides an example. Her analysis suggests that population stability is most sensitive to the harvesting of palms 10-20 m tall; population growth estimates were little affected by removal of palms over 20 or under 10 m tall.

Studies of the population biology of commercially valuable species under different harvesting regimes, combined with studies on reproductive biology, can form the basis for analysis of the genetic

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consequences of forest management. If harvesting intensities are to be sustainable over the long term, we need to know whether the resource base is deteriorating due to current management practices. Newly developed methods of genetic characterization (e.g., DNA-hybridization and electrophoresis) make studies of genetic changes in populations more feasible but still relatively expensive.

Damping Off and Other Seedling Pathogen Problems

Seedlings of most tropical tree species suffer a suite of pathogens, the best known of which are fungal. Although most studies on seedling pathogens have been conducted in nurseries (for a brief review see Evans, 1982), attack by fungal pathogens under natural forest conditions in the American tropics has been studied by Augspurger (1983 a & b). Instances of damping off (attack by *Pythium, Phytophthora,* and several other fungi) are common where seedlings emerge in dense aggregations in the shade, particularly if they are close to conspecific seed-producing trees. Seedlings that grow rapidly and have high non-structural carbohydrate concentrations are more resistant to attack, but post-germination losses can nonetheless be severe. Virtually nothing is known about relative susceptibilities of different tree species to damping off. To the extent that pathogens reduce populations of natural regeneration of commercial species, additional research is needed.

Susceptibility to and Consequences of Mechanical Damage

A growing number of forest biologists and silviculturalists are focusing their attention on the high proportion of trees that suffer mechanical damage both in natural and logged forests (e.g., Ewel and Conde, 1980; Hendrison, 1990). Less attention has been paid to the long-term consequences of this damage (but see Putz and Brokaw, 1989). We also know little about species-specific differences in susceptibility to damage, but casual observations suggest that this is worth consideration. Studies of damage have generally focused on shrubs, tree seedlings, or saplings in the understories of intact forests. The effects of logging and major storms on large trees have also been investigated but much remains to be learned.

An alarming proportion of seedlings in the understories of intact forest suffer mechanical damage from falling branches, palm fronds, etc. Clark and Clark (1989), for example, set out 500 20 cm tall model seedlings constructed from plastic drinking straws and wire; 82% were uprooted, bent, or broken during the year of their study in an old growth lowland wet forest in Costa Rica. In the same forest, Gardner (1989) found that nearly all individuals of shrubby species of *Piper* showed clear signs of having suffered damage. These shrubs displayed many adaptations for avoiding death from breakage, including the capacity of detached branches to produce roots. Other species in the understory also show high incidences of breakage. However, natural or logging-induced breakage of seedlings and saplings of commercial species has not been studied in the American tropics.

In response to windstorms and selective logging, many trees lose leaves and branches, or suffer stem breakage or uprooting. Hurricane Hugo, for example, broke or uprooted nearly all of the trees in the

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Luquillo Forest of Puerto Rico (Walker, 1991). The aftermath of Hurricane Gilbert left few trees intact in the dry forest on the Yucatan Peninsula studied by Whigham *et al.* (1991): mortality was extremely high during the years following the storm even amongst trees with resprouted crowns. In a mature Malaysian mangrove forest monitored for some 60 years, Putz and Chan (1986) reported that all trees that suffered even slight mechanical damage died within a decade of being damaged. This mangrove forest is certainly an extreme case of intolerance of mechanical damage, but species-specific responses to damage need to be determined for other commercially valuable species.

After suffering mechanical damage, trees of many species are extremely susceptible to pathogens. Ng (1985) suggested that trees with dense heartwood are actually more susceptible to heartrot than trees that do not form heartwood.[3] However, wood from the heartwood-forming species, especially the heartwood itself, is often quite decay-resistant when sawn. Ng's observations are fairly speculative but have profound silvicultural implications. Most high quality timber species produce heartwood, and thus may be particularly likely to produce heartrot after being damaged during logging. Considering that extraction of only 5-10 trees per hectare, if uncontrolled, often leads to the damage of 100 other trees > 10 cm dbh (for a review see Hendrison, 1990), decay problems during the next cutting cycle may be particularly severe. Natural forest managers need to consider, that in addition to controlled felling and planned timber extraction, silvicultural guidelines should call for removal or poisoning of some of the trees that suffer damage during logging. Hollow trees are valuable for wildlife but are not useful for timber; populations of bat-pollinated trees, however, may depend on the presence of hollow trees for their persistence.

It would be useful to know if branching patterns, bark characteristics, or season of logging influence susceptibility to mechanical damage. Trees with excurrent (i.e., spruce or fir-like) branching are somewhat rare in tropical forest, but many species have a dominant central trunk when young (Hallé *et al.*, 1978); these species may suffer less mechanical damage in polycyclic logging areas. Bark is the primary line of defense of trees against pathogens; bark removal often opens entryways for wood-rotting organisms (see examples in Agrios, 1988). Trees with thick or otherwise tough bark may suffer less damage than trees with thin bark. Also, during times of the year when the vascular cambium is inactive, bark is more tightly attached to the wood and incidental bark removal during felling and timber extraction may be reduced.

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[3] Trees of this latter type, which Ng called "sapwood trees," have living tissue (parenchyma) through the xylem from pith to bark. Although their wood is well protected against heartrot fungi while the trees are alive, sawn timber from these species is extremely susceptible to decay.

Cataclysmic Disturbances

Forest managers need to be aware of the likelihood of forest-destroying fires and hurricanes and the effects of forest management practices on a forest's susceptibility to these disturbances. For example, in both American and Asian forests, fires penetrate further into selectively logged than into primary forests (Woods, 1989; Uhl and Buschbacher, 1989). Unlogged buffer zones or the establishment of living or cleared fire breaks might be effective control measures, but there are few data upon which to base recommendations. Living buffer zones and modifications of cutting practices may also reduce the effects of wind storms. Because trees often mechanically support one another or at least buffer wind effects on neighbors (Holbrook and Putz, 1989), logging probably exacerbates storm effects. Data on this topic are not available for the American tropics but managers of forest plantations in the temperate zone differ in their approaches to buffer zone planting densities (e.g., widely spaced to promote wind-firmness of individuals or densely packed to shed the wind over the stand; Grace, 1977). No rules exist for tropical foresters to follow and research is needed.

EFFECTS OF FOREST MANAGEMENT PRACTICES ON THE ATMOSPHERE

Tropical forest managers might benefit from the increasing worldwide concern about the accumulation of carbon dioxide, methane, and other heat-trapping ("greenhouse") gases in the atmosphere. Although most foresters agree that the first step toward forest management (as opposed to timber "mining") is control of logging practices (e.g., Palmer and Synnott, 1992), few loggers have been motivated to adopt reduced impact logging guidelines. Along with its other economic and ecological advantages in selectively logged forests, application of reduced impact logging techniques (e.g., directional felling and planned extraction of logs) would reduce post-harvest emissions of heat- trapping gases from decomposition of damaged trees. Furthermore, forest regeneration and thus the rate of carbon sequestration in stand biomass is probably higher where logging damage is minimized, especially if fires or vines are likely to be a problem. Power companies, concrete producers, and other major emitters of carbon dioxide could sponsor reduced impact logging as part of their carbon-offset programs. If this is to happen, however, researchers will have to provide data on the costs and carbon-savings associated with different forest management techniques.

SOME REASONS FOR THE WEAKNESSES IN THE RESEARCH
BASE FOR NATURAL FOREST MANAGEMENT

There are innumerable reasons why the data on which to base sound natural forest management practices in the American tropics are often not available. One could focus on the obvious geographical problems, high species diversity, forest stature and canopy access difficulties, lack of facilities, shortage of funding, and bureaucratic impediments. Instead, I will concentrate on the following: deficiencies in our knowledge due to biases against forestry in the research community and among the Latin American academic and economic elite; parochialism of forestry institutions; and the reward structure for North American researchers competing for grant support.

Up until very recently, relatively few high caliber students in North America, and even fewer in the American tropics were attracted to forestry as a profession. Judging from the generally lower standardized test scores of forestry students compared to liberal arts majors in U.S. universities, this unfortunate tendency has not yet disappeared. That the author of this paper, with all its faults, and many of the most prolific researchers of natural forest management in the American tropics (e.g., C. Uhl, V. Viana, A. Gomez-Pompa, R.J. Buschbacher, B. Finegan) are basically ecologists rather than "card-carrying" foresters is also revealing.

Foresters in Latin America are held in low regard by both upper and working classes, often being perceived as no more than rural police by the latter. The unattractiveness of the forestry profession is justified at least insofar as salaries for foresters, particularly in government service, are quite low. In places where the forests themselves have no cultural mystique, young people are attracted to office jobs in the cities; to return to work in the forest would represent a substantial loss of status. In much of Latin America owners of property from 50 ha to large haciendas derive prestige from owning cattle, not from managing forest. Often with the support of governmental and local lending organizations, as well as international banks, land owners convert forests into pasture even where cattle ranching is not profitable in the absence of subsidies (e.g., Schmink, 1987).

Another reason for the weakness of the data base for natural forest management is that researchers in academia are rewarded for novel contributions to their fields and not for replicating studies in new geographical areas or with new species. The U.S. National Science Foundation (NSF), in particular, seldom funds research on well known topics, such as many of those discussed in this report (e.g., determining the shade tolerance and susceptibility to pathogens for long lists of commercially valuable species); such research is quite reasonably considered to be only of regional interest. In keeping with its congressional mandate, NSF shuns applied research in general; this is considered to be the domain of USDA, private industry, and other unspecified funding sources. Were these other agencies actually funding the research needed, NSF's position would be appropriate; basic research is important, even given the rapidly deteriorating conditions in our environment and the immediate need for research that would be useful in rectifying the situation. Unfortunately, USDA is not funding much applied research on tropical forest management. Furthermore, the funding that USDA allocates for tropical forestry is mostly absorbed by a network of researchers within the U.S. Forest Service. Perhaps the recent

establishment of new bureaucratic entities within the U.S. Forest Service that are dedicated to promoting sound tropical forestry heralds a change in this time-worn tradition.

Ecologists who might participate in trying to answer the kinds of questions facing tropical forest managers are often precluded from doing so due to lack of financial support. Due in part to NSF's mission to support basic research, the shortage of funds for applied environmental research, and to the perception of USDA and the U.S. Forest Service as being "old-boy" operations, a movement is underway to create a National Institute for the Environment (NIE). Set up along the lines of the National Institute of Health, NIE would serve as a link between basic science and environmental policy. Whether or not NIE becomes a reality, the support behind the proposed alternative to NSF and USDA clearly illuminates the perceived deficiencies in these agencies.

Ecologists employed by academic institutions and research centers, particularly in the U.S.A., are driven towards "pure" research by the tenure and promotion system. An individual advances in North American academia through conducting high profile and highly fundable research that is published in prestigious technical journals. Novel investigations are often rewarded more than solid and especially long-term research.

The symposium volume entitled "Reproductive Ecology of Tropical Plants" (Bawa and Hadley, 1990) published by the Man and Biosphere Program provides a number of examples of researchers focused on the biology of species of little or no commercial importance. This is not a criticism of basic research but it is frustrating that in the American tropics much more is known about the reproductive biology of non-commercial herbaceous understory species than about the canopy trees for which the forests are being destroyed; this makes managing forests for these tree species quite problematic.

Studies on the dynamics of old-growth forest provide another example of how ecological research neglects issues of real concern to forest management. Even the author of this paper has claimed that by investigating canopy dynamics in old-growth forest, great silvicultural insights will be revealed. In light of obvious contrasts in the dynamics of logged and old-growth forest, this is an example of misplaced research effort. Natural canopy gaps in primary forest, for example, are generally small, isolated from one another, opened by the breakage (or less often the uprooting) of one or a few trees, and result in the disturbance of little soil. Logging gaps in even selectively-harvested forests are often large, connected to one another by skid trails along which weeds readily disperse, and often involve substantial amounts of soil disturbance (e.g., removal of the litter layer and compaction). Rates of regeneration and species composition in logging gaps often differ markedly from natural gaps in the same region. Clearly, studies on tree regeneration and other responses to logging-induced disturbances should be carried out in logged forests.

Growth and yield plots provide the basis for projection of future yields but need to be established in logged forest and monitored for several decades at least. Claims to the contrary notwithstanding, rates of tree growth in old-growth forest are only weakly correlated with growth rates in logged forest. Admittedly the more common and certainly more egregious mistake is assuming that high growth rates during the first years after logging continue for the duration of the rotation; this leads to major

overestimates of yields and provides justification for unrealistically short cutting cycles.

Ecologists and silviculturists employed in colleges of forestry and forest research institutes are rewarded for doing applied research but suffer from the parochialism that seems endemic amongst foresters. Administrators of these institutions often are unwilling to hire researchers who will conduct their investigations outside of the region from which the institution draws financial and political support. Private sector funding for research seems more common in forestry colleges than in colleges of liberal arts and sciences that employ ecologists but, not surprisingly, funding from industry is generally aimed at solving local industrial problems.

Forestry research institutes in the American tropics (such as, the *Centro Agronomico Tropical de Investigacion y Ensenanza*, or CATIE) are almost uniformly academically weak or are poorly funded. Furthermore, reward systems in these institutes often do not promote field research and curricula are biased towards the plantation forestry in which the instructors were trained. Helping to build the quality and quantity of forest research and training institutions in the tropics is clearly among the best investments in forest conservation and sustainable use.

Although many millions of dollars are invested annually in tropical management and conservation by international aid agencies, development banks, and private and corporate philanthropic foundations, a very small proportion is allocated for the necessary research. The bureaucratic workings of these potential sources of funding for research are generally opaque to researchers or are sufficiently labyrinthine, changeable, and idiosyncratic to be off-putting. For all their shortcomings, the explicit proposal submission guidelines and peer review processes of the NSF and other traditional funding sources for scientific research have many esteemable qualities. Development agencies are aware of these proven evaluation procedures, but generally do not put a high priority on sponsoring the highest quality of research possible. A research component is inserted into many forest conservation and management projects more to assuage powerful and very vocal lobbies rather than as an indication of the granting agencies' belief in the efficacy of the scientific method or the potential contributions of scientists.

The lack of faith in science and scientists that seems endemic among development agency staff reflects poorly on our formal and informal science education systems. Why is the scientific method not seen as being the most cost-effective and fail-safe procedure for finding the solution to problems related to forest management and conservation? Why are scientists and particularly ecologists often viewed as financial and administrative burdens when so much remains to be learned about forest management? If researchers want to be involved in tropical development and conservation projects they must show themselves to be cost-effective and efficient at solving problems identified by project administrators. More fundamentally, the scientific community needs to provide future cohorts of development project administrators with a better appreciation of science and scientists.

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CASE STUDIES

The few well documented examples of natural forest management in the American tropics are reviewed by Schmidt (1991) on a country by country basis. Here I will provide brief overviews of three projects that employ very different silvicultural approaches but that are all aimed at the elusive goal of sustainability.

The *Plan Forestal Estatal*, Quintana Roo, Mexico

Forests of the Yucatan Peninsula have developed on a limestone plateau with mostly shallow and rocky soils, seasonal and limited precipitation, frequent hurricanes, anthropogenic and natural fires, and other severe human-induced disturbances during the past few millennia. The forests are of low stature, with the canopy usually less than 25 m high, but are often well stocked with commercially valuable trees. Not surprisingly, many of the tree species common on the Yucatan Peninsula are species that flourish under harsh soil conditions and a regime of frequent disturbances.

Since 1983 the *Plan Forestal Estatal* (PFE) has been involved in forest management in Yucatan State of Quintana Roo (for recent reviews see Arguelles, 1991; Dickinson *et al.*, 1991). While the forests managed under the PFE umbrella are used for chicle production from *Manilkara zapota* trees, they are also managed for timber. The two main target species for management are *Swietenia macrophylla* (Meliaceae: mahogany) and *Cedrela odorata* (Meliaceae: cedrela); about 15 other less valuable tree species are also harvested.

Forest management in the PFE area basically consists of selective logging of the large commercial trees on a 25-year cutting cycle and a 50-year stand rotation. This harvesting schedule and the demarcation of equal volume annual felling coupes are based on a stand model developed by PFE using growth data from mahogany trees in Puerto Rico. To foster seedling establishment and growth of the light-demanding Meliaceae, trees are preferentially felled in groups and seed trees are retained on the margins of log yards and other clearings. Enrichment planting with mahogany and cedrela seedlings is also practiced in some log yards and other areas lacking natural regeneration.

Species of Meliaceae are among the highest valued and best known of tropical trees. Dozens of research papers and books have been published on *Swietenia* alone (Putz and Pinard, 1991), with in-depth studies dating from the 1930's (e.g., Lamb, 1966). This is helpful because PFE management guidelines basically focus on the Meliaceae. Unfortunately little is known about the other 15-20 species that are harvested and that are hoped to contribute to future harvests. This is an acute problem, both because large gaps appears to be required for successful mahogany regeneration (see below) and because these lesser known species fetch low prices or have no markets at all. This means that stand improvement treatments and harvesting practices designed to foster mahogany regeneration are costly because the thinnings are not of high value.

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Many of the plantations of *Swietenia, Cedrela*, and other Meliaceae established throughout the tropics have failed to be commercially viable due to damage caused by shoot tip borers (*Hypsipyla*). However, these efforts have added to our knowledge of the seed biology of trees in this family (e.g., Lamprecht, 1989; Evans, 1982). Seedling establishment requirements are less well known, but researchers generally agree that most Meliaceae are fairly light-demanding. Factors affecting the growth and yield of Meliaceae trees after the seedling stage have likewise been little studied (but see Weaver and Bauer 1986).

Data on the reproductive biology of most of the tree species in the forests being managed by the PFE are not available. The phenological data that do exist, however, suggest that logging is carried out at exactly the wrong time, that is, when seeds are not yet mature (Snook, 1989). Enrichment planting with mahogany apparently is successful but is carried out in a haphazard way and apparently neither costs nor silvicultural benefits have been tabulated. The potential advantages of stand improvement treatments (e.g., freeing potential crop trees from competition) also remain to be investigated. The long-term prognosis of the PFE would also be improved by research on the responses of commercial trees to logging damage.

The *Plan Forestal Estatal* is a production-oriented project and has done little to promote research on even crucial applied issues. Like many practically-minded foresters, many PFE staff feel that too much emphasis is often given to research and that researchers often spend a great deal of time and money addressing esoteric issues. One manifestation of this mistrust for research is that PFE staff seem reluctant to modify their management plans in light of research results even when relevant data become available (e.g., observations of regeneration failures of mahogany under current logging practices). While the PFE is among the most successful natural forest management projects in the world, their data base is extremely weak.

The CELOS Project in Suriname

The CELOS Silvicultural System is a low intensity selective logging system designed for low impact on tropical lowland forests with very nutrient-poor soils. CELOS guidelines specify controlled felling and extraction of trees between 35 and 50 cm dbh, constituting about 20 m³ of timber/hectare. This is followed by three refinement treatments, consisting of woody climber (liana) cutting and two poison-girdling treatments of non-commercial trees that compete with advanced growth of commercial species. The logging system is "polycyclic" insofar as the cutting cycle (20 years) is shorter than a full stand rotation (i.e., from seed to merchantible-sized tree apparently requires 60-80 years). The system is described in considerable detail in four volumes from Wageningen Agricultural University in The Netherlands (for a review of the first three volumes see Putz 1988). The volumes introduce the CELOS system and present the results of stand improvement treatments (de Graaf, 1986); describe the effects of logging and silvicultural treatments on soils, water, and nutrient balance (Poels, 1987); discuss improvements of the basic silvicultural system and tabulate costs of treatment (Jonkers, 1987); and describe a logging method that is designed to reduce damage to advanced regeneration and soils (Hendrison, 1990). While the focus of these studies was mostly at the stand and ecosystem levels, enough data were collected on species-specific recruitment and growth (mostly in Jonkers, 1987) to be

convincing that this approach to forest management could be ecologically and silviculturally sustainable. Further evaluation of this possibility awaits the availability of long-term growth and yield data, collection of which awaits cessation of hostilities in the study area.

The major concern of the CELOS project researchers is sustainable timber production. The effects of repeated felling and refinement treatments on non-timber forest products, animal populations, and forest composition in general have not been investigated. Unfortunately, due to the political situation in Suriname, planned studies on other aspects of forest biology have been postponed. It is also unfortunate that the results of this in depth and multi-faceted series of investigations are not better known in North America (but see de Graaf and Poels, 1990).

The Central Selva Project, Palcazú Valley, Peru

The silvicultural management plan being tested in the Palcazú Valley in Amazonian Peru basically consists of clear-felling and complete extraction of all wood from strips cut through wet tropical lowland forest (e.g., Hartshorn et al., 1987). Although often discussed as if it were a new silvicultural method based on recent studies of gap-phase regeneration (Hartshorn, 1989), strip clearcutting was extensively experimented with more than 100 years ago in Europe (e.g., Smith, 1986; Matthews, 1989). In its modern Peruvian application, the system calls for complete utilization of all extracted wood either in a sawmill, an apparatus for pressure-impregnating utility poles and fence posts with preservatives, or charcoal kilns. The Palcazú project is noteworthy because of the degree of involvement of local people in project planning and implementation and because it is the local people who will profit from forest management (Stocks and Hartshorn, 1993).

Forest in the two demonstration strips (20 x 75 m and 50 x 100 m) harvested in 1985 reportedly regenerated extremely rapidly, initially from stump sprouts (i.e., coppice) and later from seed. Silvicultural treatments prescribed include reducing the number of sprouts per stump, cutting vines, and thinning the stands (after canopy closure) to favor particularly desirable individuals (Hartshorn, 1990).

A number of biological concerns about this project's approach to forest management project have not been addressed because of security problems in Peru. Progress toward understanding the biology of the strip clearcut system as tested in Peru is also stymied by the defensiveness of project advocates (Putz, 1992). Although clear warnings about the dangers of trying to transfer complete silvicultural systems from forest to forest have been given (e.g., Hutchinson, 1988), tropical siliculuralists continue to argue the advantages of their favorite system without due regard for variability in biological, social, and economic conditions. This tendency seems particularly strong in some tropical strip clearcut advocates and is particularly worrisome in this case due to the extremely preliminary nature of their data.

Strip clearcuts 20-50 m may fail to yield commercially valuable saw timber for a number of basic biological reasons. While many timber tree species in the area apparently have light-demanding seedlings, research in other tropical forests is revealing deficiencies in the basic "gap-phase regeneration" idea. Even some of what were described as archetypical gap-phase species (e.g., *Dipteryx panamensis*;

Hartshorn, 1980) have seedling distributions that are not closely correlated with the distribution of canopy gaps (Clark and Clark, 1987). Canopy gap regeneration is often dominated by weedy species that germinate from the bank of dormant seeds buried in the soil (Putz, 1983; Lawton and Putz, 1988), by resprouted trees damaged when the canopy gap was formed (Putz and Brokaw, 1989), or by vines (Putz, 1984). How weed infestations are avoided in the strip clearcuts is not at all clear. Furthermore, reliance on coppiced trees seems problematic since these trees are likely to develop heart and butt rots before attaining saw timber size. Finally, if regeneration depends on the rain of viable seeds of commercially valuable species from forests adjacent to the narrow strips, there might be an effect of season-of-cutting on the species composition in regenerating clearcuts.

While much remains to be learned about strip clearcutting in the Palcazú Valley, the method has several advantages over more stand-specific approaches to forest management. If it does not result in forest degradation, strip clearcutting requires concentrated silvicultural activities in relatively small areas. Low intensity "selective harvesting", in contrast, opens up vast tracts of forest to encroachment by weeds, erosion, human colonists, hunters, and illegal loggers. Furthermore, if there are accessible and substantial markets for the smaller dimension timber and species generally considered "non-commercial," strip clearcutting can be very profitable on an areal basis (Stocks and Hartshorn, 1993). The application of strip clearcutting is also straightforward and requires a minimum of training or silvicultural insight.

RESEARCH PRIORITIES

The problems faced by natural forest mangers in the tropics vary so much from forest to forest that specifying where research emphasis should be placed would be difficult at best. At worst, a list of research priorities could be used to condemn investigations crucial to the management of particular forests but that do not address issues of general concern. Clearly, a major goal for natural forest management in the tropics is to provide demonstrations of the economic viability of approaches to forest management that are ecologically and socially benign. Researchers can contribute to and benefit from the development of these demonstration forests through investigations of the key factors influencing the success of forest management programs.

Even though it may seem short-sighted, a concerted effort should be made towards assuring that forests survive the next cutting cycle or rotation. If we are overly concerned about the long-term ecological consequences of silviculture, forests will be lost that might otherwise have been managed in a reasonable, if not perfect fashion. Although natural forest management definitely has effects on ecosystem functions (e.g., watersheds and nutrient cycles), wildlife populations, and biodiversity, from a conservation standpoint it is immensely preferable to the alternatives of conversion to pastures, plantations, or agricultural fields.

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